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GRATICULES

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DEFINITION AND ORIGIN OF THE TERM "GRATICULES"

THE term "graticules" will be a familiar one to all members of this Society, but being a term which has practically originated during the war, it may not be so familiar to those not immediately connected with optics. I think that graticules may best be defined as being the measuring scales or marks, placed in a focal plane of an optical instrument, for the purpose of determining the size, distance, direction, position or number of the objects which are viewed coincidently with the scale itself. Generally the graticules are on glass and it is usual to refer to the complete discs or plates with the measuring scales or marks on them, as "graticules." It will be seen that the word "graticule" is a highly convenient general term, which comprises not only certain descriptive expressions for individual appliances, such as reticules, sighting scales, cross-lines, micrometers, eyepiece micrometers, stage micrometers, haemacytometers, but also various non-descriptive and loosely worded terms, such as diaphragms, webs, etc., which are apt to lead to confusion because they are often used for totally dissimilar purposes.

It is to the intuition and foresight of our President, Prof. F. J. Cheshire, as to the importance that graticules would and did assume in the course of the war, that their production on a commensurate scale, rivalling those made in Germany, became an established industry in this country. As I was one of those whom he stimulated and encouraged to research work on this, at the time, seemingly insignificant side line, and having devoted some 3½ years now to research on their production and two years to their manufacture in quantity, I am rather happy to know that Prof. Cheshire takes an equally optimistic view as to the importance which graticules will attain for optical instruments for peace purposes. I fully share this view and shall endeavour to justify it in this paper.

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Methods of Manufacture and History

Up to the time of the war the principal method of graticule manufacture in all countries was by ruling them with a dividing engine. They were either ruled on the glass direct with a diamond point, or they were ruled in a coating of bituminous or waxy substance, which acted as a resist to the subsequent etching of the glass, either with hydrofluoric acid fumes, or by immersion in solutions containing hydrofluoric acid. I have also reason to believe that certain forms of graticules (such as stage micrometers) have been ruled on thin coatings of a transparent film, on which a cover glass is subsequently cemented.

Such methods of ruling on glass are naturally subject to rather severe limitations. In the first place the sharpness and apparent opacity of the lines depend on the cleanness and fineness of the diamond cut, and it is well known that to obtain perfect cuts is not quite as easy as might be thought and that the diamond points for such fine work soon wear out. Secondly, the method only lends itself readily to very simple patterns such as cross-lines, or a number of similar marks at equidistant intervals, and becomes cumbersome and troublesome where the scales wanted are more elaborate, or with varying thicknesses of lines, not to mention curved lines or numbered lines. Thirdly, where one line crosses another, the glass is apt to be broken up, so that just the critical point is less good than the rest, and this has led to the practice of just stopping short of a line, or ruling up to it, and continuing the line on the other side (*vide* Photomicrograph 11), a practice which does not tend to ease and rapidity in production. Lastly, it is clear that every graticule is an individual piece of work, and there is no positive guarantee of equal accuracy and uniformity in the case of fine measuring scales, so that they require separate testing.

The ruling and etching methods have certain advantages inasmuch as the ruling point, not necessarily a diamond point, does not wear so rapidly, also the etched lines can frequently be filled in to render them opaque, and it is possible, though cumbersome in the case of fine work, to reproduce curves, numerals or letters by a pantograph arrangement. In other respects they suffer from precisely the same limitations as those ruled directly on glass, and in addition it is extremely difficult to coat them with a resist so perfect that the hydrofluoric acid does not attack the glass here and there through the resist, occasioning tiny spots or marks which are objectionable. These ruling methods are therefore only suitable for graticule production to a very limited degree.

In Germany two other methods had been developed, the one being a regular photographic method (the most familiar examples are microscope micrometer eyepieces), and the other a ceramic method, by which a yellowish, or sometimes a bluish-grey granular image was obtained on the glass itself. Both these methods are secret processes, practised by one or two firms only, which had obtained a practical monopoly of the products, and neither in this country, nor so far as I am aware, in any other country outside Germany or Austria, was the knowledge available for their production, nor had any serious attempt been made to produce them.

There is some evidence to show that the German photographic method followed

on the lines of the collodion processes in the days of old, possibly the Taupenot process*, or a modification of it. These processes are rather long and complicated, but have the merit of yielding results of exceedingly fine grain†. Photographs of very fine grain have also been produced in France commercially. I may remind you of the photomicrographs on the plane side of a little lens, placed in the ends of penholders and other fancy articles, which had a vogue many years ago. Also in this country very fine grained photomicrographs have been produced formerly, notably by a Mr Barker, who had some secret process, but with his death the secret was lost. Whether these methods were applied to graticules, I do not know.

From the points of view of accuracy, uniformity and ease of production in bulk, as well as the possibility of producing to any desired scale patterns of any kind, including those with figures or numbers, photographic methods offer such obvious advantages, that numerous attempts have been made to realise them both here and elsewhere. These have failed for several reasons; firstly, ordinary photographic processes are not well adapted for such fine work, as they are all granular and have to be subjected to what may be called more or less violent treatment to bring them into a form available for graticules; secondly, in the case of granular emulsions it is almost impossible to get the clear part of the film *absolutely free* from specks and spots, not to mention dust specks, to which gelatine films are peculiarly prone; thirdly, the films have a tendency to milkiness or cloudiness, which cannot be entirely removed even by cementing a cover glass on them; fourthly and lastly, for numerous purposes, more particularly in optical munitions, as it is undesirable to have graticules with a cemented cover, the marks should be on the glass itself and as permanent and free from liability to damage as possible.

As regards the German ceramic method of producing graticules, which so far as I am aware has been strictly confined to the production of graticules for binoculars, in which the comparatively faint lines which they secured by the process are of advantage, no literature at all dealing with their production could be found, nor any references, and the fact that they have been produced by photoceramic methods has been deduced from the examination of certain specimens.

Mr J. E. Barnard, President of the Royal Microscopical Society, first suggested that they might possibly have been produced by such means, Prof. Cheshire had the image lines analysed on behalf of the Ministry of Munitions, and I consider that I have been able to find indubitable proofs that Mr Barnard was perfectly correct, and moreover that the specimens were produced by two somewhat different methods, indicating possibly that two firms had the secret of their manufacture and had worked it out along different lines.

Though the facts mentioned in this paper are all familiar enough to me now, they were not so when I first started research on the matter in the summer of 1915. The advantages of photographic methods for production in bulk were, however, so apparent, that investigation by such methods was at once decided upon.

* For accounts of these processes see Hardwick's *Photographic Chemistry*, 1859.

† *Vide* "Fine grain Photographic Plates," *British Journal of Photography*, Sept. 13, 1912.

In experimental work on colour screen plates, upon which I had spent some years, I had discovered and patented new methods, by which colours could be introduced into, or extracted from a collodion film through a superimposed photographic resist, the action of the light during exposure causing the resist to become porous and permeable to the dye solution in the image lines or dots. The resist could subsequently be washed away. A few months experimenting on these lines, however, showed the method to be impracticable so far as graticules were concerned, as the results were not sufficiently clean for this purpose, nor was the thickness or rather fineness of the lines under sufficient control.

I then decided to try and evolve some means of photo-etching, based on a modification of the same idea, viz., that the photographic film should now be of such a nature, that the action of light on it produced permeability to hydrofluoric acid fumes, whilst the parts of the film unacted on by light should at the same time act as a resist to the fumes. This proved perfectly feasible; a suitable photographic film was gradually evolved and in the course of twelve months' work on these lines photo-etched graticules were produced experimentally, yielding beautifully fine lines. A few of them are exhibited this evening, and I believe they represent the finest photo-etching work on glass that has been done.

Unfortunately, however, this photo-etching has not proved of any practical use for graticules. In the first place it was not found possible to get the photographic resist so perfect that the hydrofluoric acid gas would not here and there act through some weak spot or pinhole, producing those tiny micro-markings in the nature of pits, which have to be avoided; but more important than this defect, which might after all have been overcome in time, is the fact that such fine etched lines show up properly by transmitted light, only when the pencil of illumination is comparatively narrow and become increasingly difficult to see when the cone of light becomes wider, until ultimately they almost entirely disappear. This would therefore limit their use to entirely exceptional cases. Filling in the lines was tried, but the nature and configuration of the etched lines, which in section had rounded rather than sharp edges, were not suitable.

Meanwhile the research on the photo-etching brought out the necessity of having negatives with lines as sharp and as clean and as free from all grain as possible, and here again I was fortunate enough to be able to draw upon the results of some experimental work carried out in 1914 for another purpose, during which I almost accidentally discovered a new method of preparing a completely grainless light sensitive collodion. Based upon this a large number of experiments were carried out which, within a few months of relinquishing the photo-etching methods, resulted in the process which I have termed *Grainless Photography*, and which was almost immediately a great success, as it fulfilled most of the desiderata for graticule production. As this process has not been patented and is being kept secret, I cannot enter here into further particulars, beyond stating that not only the composition of the collodion film itself, but also its treatment, differs widely in many respects from ordinary photographic practice.

To start with there was still some little trouble in getting rid of every trace of

cloudiness in the films, but this was in time completely overcome. The grainless photographic graticules in short avoided every shortcoming of previous attempts at producing graticules photographically, except one, viz., that they were not available in cases where it was absolutely essential to have permanent and irremovable marks on the glass itself, without any film or cemented cover glass, a point especially desirable for many optical instruments for munition purposes. It took a further eighteen months' continuous research to solve this problem; the result was the production of graticules by what I have termed *Filmless Photography*, in which the image lines are formed in the surface layer of the glass itself in untarnishable metal. The image lines, which are grainless, may be opaque or transparent, as desired, in black, grey, or amber colour, and a perfect filmless photograph can neither be rubbed nor cleaned off in any way, as it is unaffected by solvents save such as attack the glass itself.

Here again, as the process is being kept secret, I cannot divulge particulars, but it is based on the idea that as glass is porous, though the pores may be ultra-microscopic, matter in a suitably fine state of division can be introduced into these pores by appropriate methods.

Although filmless photography was an instantaneous success, it nearly came to grief at the start for Optical Munition purposes, for which it was particularly wanted, owing to a totally unexpected and very baffling trouble which presented itself, viz., that the reverse side of the disc to that having the image lines developed small pits or pock marks during the process, although the image side remained perfect. I must here record my indebtedness to Mr A. C. W. Aldis, of Messrs Aldis Brothers, Birmingham—the first firm to take up both grainless and filmless photographs to any extent—who was sufficiently imbued with the possibilities of the new process to be exceedingly patient and helpful during a considerable period of trouble, till means were found of overcoming this objectionable feature. The means employed proved to be so automatic, that once found it was no longer possible to produce the defect, even when an attempt was made to do so.

Reference must here be made to one further method of graticule production. Messrs Adam Hilger, Ltd. have developed during the war a photo-ceramic method yielding very beautiful results, which differ alike from the German photo-ceramic graticules and from graticules produced by filmless photography. The image is a granular one, the grain however being very fine; it is not in, but firmly adherent upon, the glass surface and will stand the necessary amount of rubbing or cleaning with the usual solvents. The graticules which I have seen were of the coarse lined description, i.e. with lines about 1/200″ width, the image being black and opaque. Whether the method is intended equally for fine line graticules, I do not know.

By the kind permission of Mr J. E. Barnard, President of the Royal Microscopical Society, I am able to publish a series of photomicrographs (see plates I—IV) which he has taken of graticule lines produced by various processes. The photographs, being all taken under identical conditions, illustrate in an admirable manner the peculiarities of the different results. It should be noted that a grey or dirty background shows that the image lines are lacking in contrast; where the

image lines are quite opaque or show strong contrast, the background is clear and white in the photographs.

Considerations relating to Photographic Methods of Producing Graticules and Special Features of Grainless and Filmless Photographic Graticules.

Reference has been made to the advantage of photographic methods of graticule production for securing accuracy and uniformity of results, but to ensure this certain conditions have to be complied with.

In many photographic processes, such as the carbon process, and in some of the old collodion processes, as well as some of the old photo-ceramic processes, there is a transfer of the film on to its final support. There is some evidence to show that in some of the foreign made graticules film transfer has been effected. Now any transference of a thin film from one support to another is bound to lead to expansion or contraction; in the most favourable case it is an even expansion or contraction, in unfavourable cases it is local. Any film transference during the process of production therefore disturbs accuracy and uniformity, and is in fact inadmissible in producing graticules, since this demands the highest accuracy and uniformity possible.

In the grainless and filmless photographic processes no transference of film takes place, and to test the order of accuracy obtained we sent to the National Physical Laboratory six grainless scales and six filmless scales, taken at random out of batches which had all been produced from the same master negative (but not actually from the same negative, as a master negative serves for making any number of the actual negatives used, by means of intermediate positives). The report received, accompanied by graphs, showed that the maximum error in any of the scales, either as regards overall length or as regards the divisions, did not exceed one-twentieth per cent. As this error includes both any actual error in the master negative, in addition to the errors of variation between the separate scales, and also errors arising through the processes of turning the master negative into a positive, and of making the working negatives from it, it will be seen that the degree of accuracy and uniformity attained is almost astonishingly high. The twelve scales subjected to the above tests were 10 mm. in length; smaller numbers of filmless scales up to 100 mm. in length were likewise sent for testing and they corresponded to the others inasmuch as the maximum variations between them were less than one-twentieth per cent., in some cases very much less.

The next point germane to all reproduction by photographic lenses relates to the limits of accuracy set by the lenses themselves. An ideal photographic lens would be one which produces an image equally sharp on a flat plate over the whole field which it covers, at whatever aperture the lens is used, and with accurately equal magnification or reduction over the whole of the field. Every lens computer knows, however, that these and various other conditions cannot be rigidly complied with, and that actually a photographic lens represents a compromise between these. For all ordinary purposes the conditions are indeed amply fulfilled in the best existing lenses—no small tribute to the lens computers' skill—but graticule work

and scale work of like description bring out the limitations. Thus it is difficult by photographic reduction to secure lines of a fineness less than 1/2500" over more than a comparatively narrow angular field; with extreme care it has been possible to secure lines of a fineness of 1/5000" with Zeiss Micro Planar objectives over a moderate angular field.

In ordinary photographic work the emulsion itself, together with the method of development, would set the limit as to fineness of lines, rather than the lens, but in grainless or filmless photography the latter determines it. As evidence of this we have recently reproduced lines 1/12500" wide from original diamond rulings by contact methods.

Again in long scales of say 4" length, or greater, produced photographically from large charts, slight errors may occur in the accurate spacing of the divisions, due to the zonal differences of magnification, unless lenses of very long focus are used for the work.

In practice these difficulties are overcome very simply in the grainless and filmless processes, as where very long scales are required, or lines of a fineness less than 1/5000", originals ruled with a dividing engine are used for producing the master negative, by contact printing.

The vehicle bearing the image plays of course an important part in graticules produced photographically. Collodion has in general been found to be the most suitable vehicle, and grainless photographic graticules are on a collodion basis. Such graticules can be produced on any kind of glass. When we come to filmless photographic graticules, however, the vehicle bearing the image is the glass, or rather the surface layer of the glass itself, and consequently the kind of glass is an important matter. The most suitable kinds of glass have been found to be the various descriptions of crown glass and plate glass. With more or less trouble it has been found possible to produce filmless photographs on other kinds of glass, e.g. Baryta Light Flint, but in general, glasses containing any appreciable proportion of lead, i.e. Flint glasses, are unsuitable.

Varieties of Graticules for different purposes and some of their Optical Properties.

The majority of graticules are required for use with transmitted light and for most of these it has hitherto been customary to use graticules having opaque black lines, probably because such graticules produced either photographically or with etched lines filled in, have been the only kinds generally known or commercially available. By the methods of grainless photography, and also of filmless photography, graticules with completely transparent lines, or with semi-transparent lines, can be produced just as readily, either in tones ranging from light grey to transparent black, or in amber coloured tones, or indeed in various other colours, and I venture to doubt whether the advantage of transparent lines over opaque ones has ever received adequate attention or consideration.

The optical difference between a neutral coloured transparent line and an opaque one is that the former reduces the light by a definite percentage, whether the

object be bright or dark, whereas the latter in either case stops all the light. There would appear to be a generally prevailing impression that transparent lines will not stand out sufficiently against a dark ground, or show sufficient contrast, but the experiment has only to be made of using dark grey or black transparent lines against any object or background however dark it may seem normally to be, to find that much greater contrast is secured than might be expected; in fact in the majority of cases no loss of necessary contrast is experienced at all. When used against backgrounds or objects of light or medium depth, the gain is comfort to the eye, and loss of fatigue is most appreciable. When there are many opaque lines or anything in the nature of squared lines, or a repeated pattern, the excessive contrast of black opaque lines against a light background not only becomes positively unpleasant, but also may hinder the eye in picking up and inspecting critically the object to be viewed. A further outstanding merit of transparent lines is that they do not cut off any part of the object viewed, which is a not unimportant matter where the lines are fairly coarse, i.e. exceeding ·001", and far coarser lines than this are frequently required for various kinds of graticules.

Of course there are many purposes where opaque lines are undoubtedly best; simple cross-lines, or micrometers with exceedingly fine lines may be mentioned by way of typical examples, but I think in future the question of transparent *versus* opaque lines might well be considered on its merits according to the purpose for which the graticule is wanted.

For one class of graticules, viz., binocular graticules, transparent lines have been in use for a considerable time, as the German ceramic graticules with comparatively faint lines were used prior to the war. Etched lines not filled in, or lines ruled on the glass direct have also been employed. This is a typical example where quite faint lines are of benefit, as they do not distract the eye from the object, and are indeed, as our President puts it, only seen when they are wanted to be seen, and attention concentrated on them.

Graticules of another class are intended for use both with transmitted light and with reflected light and in general it is desired that with transmitted light the lines should appear black, and with reflected light they should appear white. They are typically employed for the class of instrument where sighting has to be done both by day and by night, and for night work the reflected light is obtained from a small subsidiary lamp, which illuminates the edge of the disc. The light so entering the graticule disc through its edge at a small angle is imprisoned by total reflection, and cannot get out of the glass, except where it impinges on the image lines which will reflect some of the light towards the ocular lens. This class of graticule, of which before the war apparently little use was made, was produced in Germany by the ruling and etching method and filling in the lines with a white opaque substance. They are now produced by my firm by a modification of the grainless process, the lines being white and opaque and I believe yielding a more brilliant reflection than the former German product. It is a class of graticule which should be susceptible of development and application to many more uses than those to which it has hitherto been put. I will only name one as an example. The cross-lines in spectro-

scope eyepieces are very unsatisfactory, as when black they are not clearly visible against the very dark ground, and when yellow or white they are not in focus on the retina simultaneously with the coloured lines of the spectra which may be under examination. Means can easily be devised for using a white grainless photographic graticule in the eyepiece, and illuminating it through the edge by light of approximately the same colour as the part of the spectrum under examination. Mr Martin, of the Imperial College of Science, has already made a few initial experiments in this direction.

We next come to graticules for use with reflected light only. Such graticules are usually so placed that light can be reflected on their surface, either directly or by means of reflectors prepared with some white diffusing substance. Their method of manufacture is ordinarily the same as for graticules to be used with both transmitted and reflected light.

This brings me to an illustration of an important, but I fear usually quite neglected matter, viz., the importance of the instrument designer keeping in touch with the graticule manufacturer as to the exact purpose for which a graticule may be required, and its precise method of use.

In all ordinary cases a graticule is so mounted that the plane of the graticule disc is parallel with that of the lenses of the optical system with which it is used. For certain munition purposes white reflecting graticules had to be viewed obliquely by the optical system at continuously varying degrees of obliquity, whilst the source of the reflected light remained more or less constant. It was then found that whilst the graticules were brilliantly reflecting when viewed at certain angles, their brilliancy was greatly diminished when the obliquity was changed. The problem therefore was to produce image lines which would reflect light equally in all directions, no matter what the incidence of the impinging light, and not as is usually the case, to have lines which will reflect the majority of the light in a narrow concentrated cone perpendicular to the plane of the graticule disc. Once the conditions were known, the desired class of image lines was not difficult to discover, since the conditions were analogous to those of lines which would yield the maximum brilliancy of image under dark ground illumination with the microscope, allowing the light to impinge on them at various angles of obliquity.

The problem was satisfactorily met by devising a new process, which I have termed the *Silverline* process, and which in effect is a kind of filmless photograph process in which the lines are produced on the glass surface, and not in the surface layer. In this particular process the lines are composed of pure silver, and instead of being grainless, they consist of a fibrillar interlaced network with exceedingly small meshes. They therefore function much in the way that irregular diatom structure would act in diffusing light equally in every direction, no matter at what angle it impinges. The lines are protected with a varnish, or with a cover glass, since they will not stand rubbing or scratching.

The graticules of the next class have clear lines on a black opaque ground; they are illuminated from behind, either by daylight or by a separate source of artificial light. I am not aware that this class of graticule was much employed in any instru-

ments before the war, nor, if they have been used, how they were manufactured. The grainless method has provided an ideal method of production, since the lines, however fine, have perfectly clean edges and are perfectly clear and transparent. These graticules are mostly used in the type of instrument in which it is desirable to project graticule lines etc. in the image plane, but in which either because there is no real focal plane in the instrument itself, or for other reasons of design, it is not convenient to place a graticule in the main optical system.

The device usually employed is to place the graticule in the focus of a collimating lens, and place a semi-transparent reflector in the main optical system at an angle of 45°. The graticule image is then seen by reflection from this, in the image plane in focus with the object itself, which is viewed through the semi-transparent glass by transmitted light. Numerous valuable optical instruments for munition purposes have been devised along these or similar lines. It is quite possible to fit graticules to Galilean binoculars (which of course have only a virtual focal plane) in this way. I made an experimental model myself, but since Galilean binoculars are not much used for war purposes, and graticuled binoculars are not used much for peace purposes, I am not suggesting this as a valuable improvement in optical apparatus.

Graticule Design.

There has, so far as I know, been no literature available to assist the designer of optical instruments in the design of graticules; any little information he may have wished to know could only be gathered from isolated facts culled here and there, or from his own personal experience, but with the means now available for producing graticules of many descriptions and having different optical properties, a few words on this subject may not be amiss.

It has, I think, scarcely been sufficiently realised that the graticule, which is often an essential and sometimes a vital part of an optical instrument, should be so designed as to secure the maximum amount of efficiency and the greatest amount of comfort in use, and to ensure these desiderata it is absolutely necessary that it should be properly co-related to the conditions under which it is used and to the general optical system of the instrument.

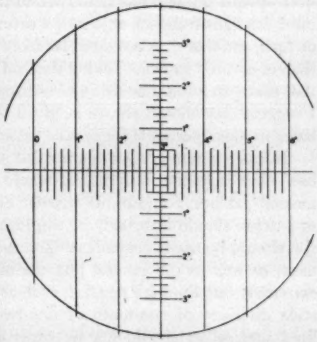
It is necessary to consider:

(1) The nature of the pattern.
(2) The thickness of lines.
(3) Question of opacity or transparency.
(4) The colour.
(5) Special optical desiderata.
(6) Questions affecting price or difficulties in production.

Regarding the nature of the pattern, one advice only can be given, that is to keep it as simple as possible. Every superfluous line, figure or other mark should be eliminated, for these only occupy the field otherwise wanted for examination of the object, and distract the eye. Repeated patterns are peculiarly irritating to the eye, and may easily *prevent* picking up of detail, unless precautions are taken. My excuse for emphasising these almost self-evident facts is that they have repeatedly

been ignored. Designers, apparently happy that they could now obtain graticules with as many lines, curves and figures and other marks upon them as they pleased, without adding correspondingly to the cost, have time and again during the war demanded complicated patterns, which after practical trials have been simplified and still more simplified, until ultimately quite simple designs are arrived at.

As an example of what I consider a faulty design the following pattern will serve; it is one which has not yet been revoked, so far as I am aware. Take the figure 3 blocking up space in the centre of the field. That could be cut out without any loss. And why put in all the degree (°) marks, which are absolutely useless and only hurt the eye. If necessary to indicate on the graticules that the numbers show degrees, one degree mark at the end of each row of figures would suffice. In other respects too the whole pattern is a peculiarly uncomfortable one for the eye, and could probably be cut down considerably, with gain instead of loss in efficiency.



With regard to line thickness of graticules there are quite a number of interesting little points which should be borne in mind and balanced. (In discussing these it may be convenient to remember that a line 1/1000″ wide, viewed with the unaided eye at normal, i.e. 10″ distance subtends an angle of about 20 seconds.) An opaque line seen against a white ground will appear rather thinner than it actually is, as the white light encroaches on the two edges of the line, by irradiation of the eye. If the opaque line is too narrow the line appears faint and indistinct, and begins to be uncomfortable. With the unaided eye a line of 1/500″ (= 1/20 mm.) is sufficiently narrow for comfort. For eyepiece graticules the magnification of the eye lens has to be taken into consideration, but the best rule for comfort is not to have the lines narrower than needful, and with eyepieces of moderate power (i.e. × 5 to × 8) opaque lines of 1/2000″ (= 1/80 mm.) will be found sufficiently fine. In micrometer scales divided into tenths or twentieths of a millimetre, the width of the lines may reasonably be reduced to 1/5000″ (= 1/200 mm.).

Transparent lines seen against a white ground always appear markedly narrower than opaque ones of similar width. In part this is due to the greater encroachment on their edges by irradiation. Transparent graticule lines should therefore be made wider than opaque ones to obtain the same effect and it is rarely advisable in an eyepiece graticule to go below 1/1000″ in width. There is less necessity to trouble about the width of line, because, as already pointed out, they have the important advantage that the object viewed can be seen through them, and can be centred to the middle of a transparent line with extraordinary accuracy. This feature is also

useful because lines of varying thickness can conveniently be used on the same graticule disc, for the sake of differentiation, without sacrificing anything in accuracy of measurements.

A peculiarity about transparent lines is that their apparent depth of tint varies with the magnification. A grey line of 1/500″ may look almost black to the naked eye, in an ocular × 5 it will appear grey, in an ocular × 10 a lighter grey, on the microscope stage magnified 100 times it will appear quite a light grey. This is a feature which should not be overlooked.

There can be no question as to the greater comfort in the use of transparent lines over opaque ones; it has already been pointed out elsewhere that their action is to diminish light from the object by a definite percentage, whether that object be light or dark, and that they stand out far more visibly against seemingly very dark grounds than one would expect. Taking this and their other advantages into account, I think that more use should be made of transparent lines than has been done hitherto, and I suggest they should always be given the preference over opaque lines, unless the latter are indispensable for special reasons necessitating *maximum* contrast.

In cases where graticules are ruled in squared lines, or where the whole surface has other repeated patterns, or where there are any markings in the nature of massed patches, for example circular discs or filled out squares, transparent lines or patches should invariably be employed in place of opaque ones and the depth of tint should be made dependent upon the magnification under which they are to be used, as well as the general purpose of the graticule. On the other hand, when extremely fine lines are needful, such as for example in micrometer eyepieces with scale divisions of one-tenth or one-twentieth mm. and where consequently the lines themselves should not be wider than 1/100 to 1/200 mm. (i.e. 1/2500″ to 1/5000″), opaque lines should have the preference, because the transparent lines would appear unduly faint owing to the irradiation effect.

Next as regards colour. The fact that graticules can be produced not only opaque or transparent, but also in differentiated colours lends itself to obvious purposes. For instance, in cases where one scale is measured against another (microscope stage micrometers and eyepiece micrometers offer familiar examples), there is clearly an advantage that one of them should be coloured differently from the other, thereby distinguishing the two sets of lines at a glance and avoiding confusion. As the scale in permanent use should in general be black or grey, it is the reference scale which should have a distinguishing colour; the actual colour is of no particular moment so long as it is clearly visible. For instance, I would have a black eyepiece micrometer 10 mm. in tenths and an amber brown or bluish stage micrometer. By way of further combining the advantage of colour and transparency and securing still greater ease, contrast, and accuracy in use, the stage micrometer instead of having separate lines every tenth or hundredth of a millimetre, might conveniently have alternate clear and coloured bands say one-tenth or one-twentieth millimetre width, the edge of the bands serving as the reference mark instead of the separate lines.

Next there are instances where it may be advisable to have some differentiation

of lines on the same graticule. Hitherto such differentiation has consisted mainly in having certain lines thicker than others. Cases occur however where it is far more convenient to differentiate by having lines of different colour on the same graticule, or perhaps one set of black opaque and one set of coloured lines. This idea was first suggested by Messrs Aldis Brothers for a special purpose, and has been patented by them. Such graticules are known by the name of Composite Graticules. Assuming such a graticule to consist of black or grey and coloured lines, the colour of the lines should be chosen in accordance with the purpose for which the graticule is destined (in so far as it is possible to produce such colours); for example, to obtain contrast against green foliage, a violet tone would be suitable; to obtain contrast against a blue sky, golden amber tones would be preferred. The only drawback to composite graticules is their relatively high cost, since the amount of work on them is just doubled. They are usually made by doing the different colours in grainless photography on two separate discs and cementing together. They have also been produced experimentally in filmless photography on the same disc.

Other special optical desiderata which the graticule should possess will depend chiefly on the methods of illumination under which the graticule is to be used, i.e. whether by transmitted or reflected light or edge illumination, whether the graticule is to be viewed normally to its surface or obliquely, whether to be used in conjunction with colour screens, or light modifiers, and any other considerations of this kind. These matters have already been referred to in the previous section of this paper.

Lastly, the graticule designer requires to know sufficient about the processes by which the graticules are to be produced, to enable him on the one hand to obtain the finest results and on the other hand to avoid specifications which unduly increase cost without increasing efficiency. The few remarks I have to make on this point will refer more particularly to photographic graticules.

Photographic graticules are usually produced from large drawings, an intermediate reduced negative is produced from these, and this finally reduced to correct size in a precision camera. Drawings should be made of a size to suit the graticule maker; in our own work it is found that from 12″ to 15″ diameter is a convenient size. Drawing to any exact scale of magnification is not needful, since they have to pass through the intermediate reduction stage. But what is important is that the thickness of lines of the drawing should be properly adjusted to the process. In all camera work lines become increased in thickness, and it is found that for grainless and filmless photographic work the lines intended ultimately to be:

1/500″	should be drawn about	5 %	thinner than the scale magnification				
1/1000″	,,	,,	10 %	,,	,,	,,	,,
1/2500″	,,	,,	50 %	,,	,,	,,	,,

In graticules made by other photographic processes the percentage of adjustment may differ and would in general be greater.

Drawings should be on smooth, thick Bristol board, not on thin board or paper

which has any tendency to cockle. The nature of the ink employed is very important for fine work, and I have experimented with a considerable number of Indian inks and have found Winsor & Newton's Mandarin black to be far and away the best ink for photographic reproduction.

In designing a graticule, if very fine black lines are required, it is inadvisable to have very coarse lines in immediate contiguity, as the treatment for fine lines differs from that for coarse lines in all photographic processes. Also it is desirable wherever possible to refrain from lines right up to the edge of a disc. In photographic and indeed nearly all processes it makes all the difference whether lines are required right up to the edge of a disc or plate, or whether 1 mm. or even $\frac{1}{2}$ mm. from the edge can be allowed free from pattern. By a trifling alteration of design of the instrument, enabling a slightly larger cell for the graticule to be used, without alteration of cost or efficiency, the cost of production of the graticules may be considerably lowered. This is a point rarely considered by graticule designers.

Finally, the question of the glass to be used for the graticules, its optical and other properties, and the saving in cost which can be effected by a proper appreciation of what is necessary and what is superfluous for efficiency in use of the graticule, hardly comes within the scope of this paper, as it depends so largely on the construction of the instrument in which the graticules are to be used and their position in that instrument. But from personal experience I may say that the matter repays careful consideration by the instrument maker, as occasionally considerable economies can be effected without the slightest loss in efficiency.

The Future of Graticules and the New Processes by which they are produced.

Now that, as a result of the war, graticules are no longer confined to a few descriptions "made in Germany," and that antiquated processes of manufacture which impose severe restrictions both as regards their design and output have given way to various new processes, which leave free scope for any desired designs, and permit of a large variety of results suitable for diverse optical conditions, to what uses may these be put?

The processes of grainless and filmless photography add, I think, a new and useful weapon to the armoury of the optical instrument designer, which if correctly made use of, may not only lead to improvements and modifications in existing types of instruments, but might easily lead to completely new types. Indeed there has already been a tendency during the war to design classes of instruments which, but for the facility with which the unusual types of graticules demanded could be produced, would hardly have been practicable. When it is borne in mind for example that a completely divided circle can be produced with great accuracy, of any size however small, with little more difficulty than a simple straight line, it suggests itself at once that instruments might well be designed where such graduated circles are either placed in or projected into the image plane of optical instruments and by suitable design of the instrument might even supplant the large and expensive

separately graduated metal arcs and circles with their separate reading microscopes elsewhere. The principle of arranging instruments so that measurements may be directly read off in the image planes at the same time as the object is observed seems to me to be one which will well repay study, and that it has not hitherto been more widely applied to various types of measuring instruments is I take it largely due to the fact that no suitable graticules could be obtained.

Again, filmless photography, which enables two scales with their images in complete contact to be freely moved one over the other, or rotated one about the other, without risk of damaging the fine lines, opens the way for arranging verniers directly in the image plane of optical instruments. Regarding verniers, by the way, in other parts of optical instruments, it has frequently been a difficulty that the two scales are not in the same plane, and that owing to this, and to the method of lighting up the verniers, errors in reading due to parallax arise. With transparent scales in which the image lines can be passed freely above one another in the same plane, this would be avoided.

Non-parallax transparent glass scales for measuring off distances on charts with great accuracy, by the aid of a lens, are a further type of optical appliance in the nature of a graticule. Reference has already been made to the use of graticules with opaque tinted lines as Draughtsman's Scales, for measuring the width of fine lines. Similar devices could readily be applied to counting purposes for the textile industry. They can in fact be applied to almost every class of counting purpose in optical apparatus, from haemacytometers onwards to large plates ruled in squares or other designs.

In photographic apparatus graticules have already been used in certain classes of focus finders; the ground or clear glasses of the focussing screen can likewise be provided with filmless photographic images in squares or other desired patterns.

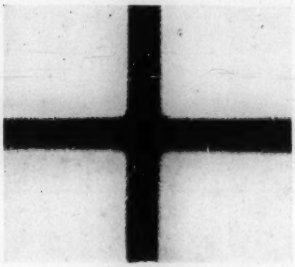
In prismatic compasses the compass dial could readily be produced as a graticule reflecting far more light in the desired direction than is at present the case.

In spectroscopes graticules illuminated through their edges by light of approximately the same colour as the spectrum lines under observation, is a suggestion already put forward. Another suggested modification for certain kinds of spectroscopes would be to have graticules for the slits, in place of the steel slits. A series of such slits in steps of definite widths could easily be arranged on a grainless photographic graticule slip and advantages may be expected from the fact that the film has probably less thickness than the knife edges of the spectroscope jaws, so that no stray reflections, etc., can occur from the edges, also that no dust can accumulate between the edges of the slits, further that the width of the slits would be of known accuracy for repetitive experiments, not to mention the question of economy in production.

I trust I have shown, by way of a few examples which suggest themselves offhand, how the application of new kinds and forms of graticules may play their part, perhaps even no small part, in the development and improvement of many types of optical apparatus.

Of the ultimate future of graticules, so far as their scientific importance is concerned, I feel confident. I wish I could speak with equal confidence concerning the outlook of the graticule industry in this country. That is a totally different question. For munition purposes it is a "Key Industry," for peace purposes the quantities required may prove to be too small for a period of years to warrant the continuous expense, on the part of private individuals or a single firm, of an organisation devoted to their manufacture and to research on the problems connected therewith. In the interests of the optical industry the continuance of some such organisation, and on an adequate scale, would certainly seem desirable. On the question whether that can be achieved or whether the study and manufacture of graticules will meet the not unusual fate in this country of scientific endeavour, which is not an immediately paying proposition, I would sooner venture no prediction.

Photomicrographs taken by J. E. BARNARD, F.R.M.S.



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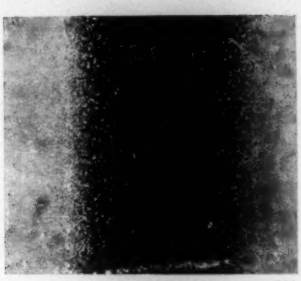

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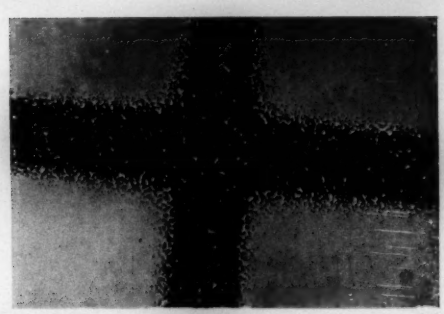

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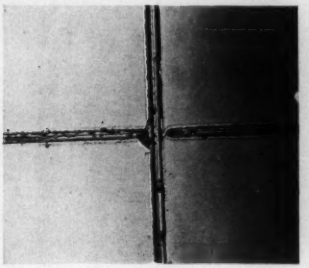
GERMAN COVERLESS PHOTOGRAPHIC GRATICULES (pre-war).

1, 2, 3, 4. Dark semi-transparent. Line thickness ·002″.

No. 3 shows deposit partly on surface, removed by scratching.

5. Yellow-grey semi-transparent.

Photomicrographs taken by J. E. BARNARD, P.R.M.S.



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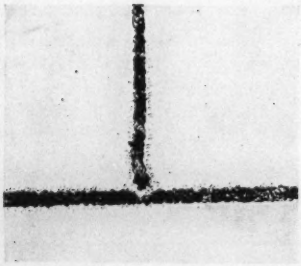

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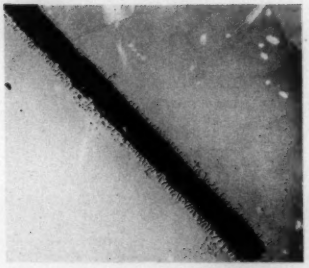

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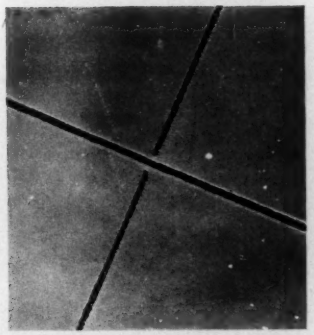
10 ×85



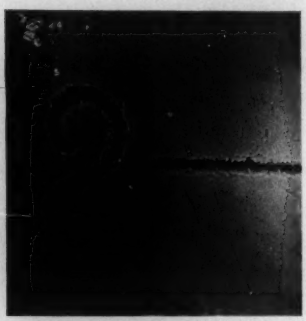
11 ×85

6, 7. DIAMOND RULED GRATICULES (look fairly dark by transmitted light). Line thickness ·00075".

8, 9. DIAMOND SPLINTER RULED GRATICULES. (9 subsequently filled in.)

10, 11. GERMAN ETCHED GRATICULES. (10 moderately dark by transmitted light owing to ground-glass effect. Line thickness ·0004".)

Photomicrographs taken by J. E. BARNARD, P.R.M.S.

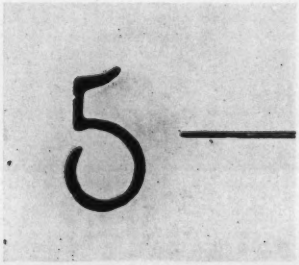


12 ×85

13 ×85

RHEINBERG PHOTO-ETCHED GRATICULE (semi-transparent).

Process not brought out commercially, as after 12 months' experimenting it was seen that the development of other methods would be likely to yield superior results.

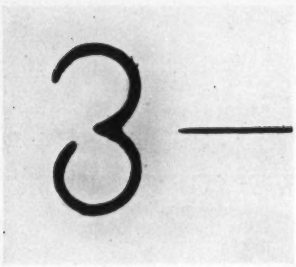


14 ×85

RHEINBERG GRAINLESS PHOTOGRAPHIC GRATICULE.

Black opaque. Line thickness ·0004".

Photomicrographs taken by J. E. BARNARD, P.R.M.S.



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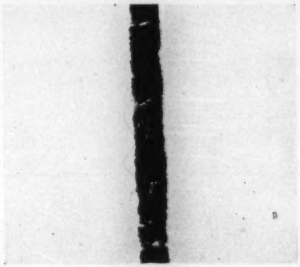
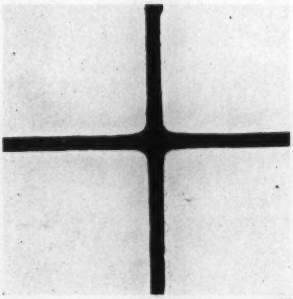


16 ×650



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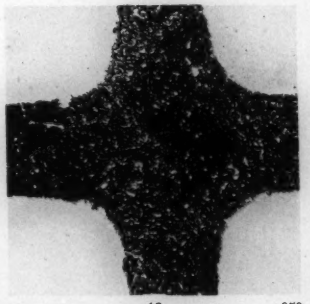

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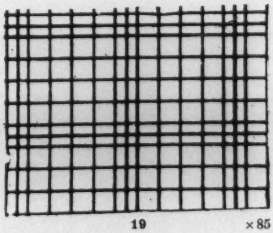

19 ×85

RHEINBERG FILMLESS PHOTOGRAPHIC GRATICULES.

15, 16. Black opaque. Line thickness ·0004".

17, 18. Black opaque. Line thickness ·001".

19. Grey semi-transparent. Line thickness ·0002".

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LECTURE ON POLARISATION

By Professor F. J. CHESHIRE, C.B.E.

Delivered 8th May, 1919

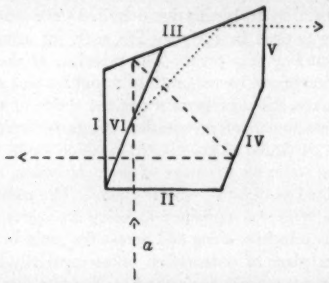
The lecturer commenced by explaining that polarised wave-motion was the common form of wave-motion noticed in everyday life, such for example, as the passage of ripples over the surface of a pond. The principle of the "polariscope" was illustrated by the action of two barred gratings through which a rope was stretched, and the analogy between this arrangement and the action of a pair of tourmalines pointed out. The production of polarisation effects by heating and mechanical stress was shown. In particular an experiment in which a cube of glass was plunged into a tank of boiling water on the stage of the polariscope, was shown. Double refraction was explained as due to "optical grain." The passage of light through a double-refracting crystal was explained as being analogous to the sound waves passing with different velocities along and across the grain in wood. The subject of the rotation of the plane of polarisation, more especially in quartz, was dealt with and many experiments were performed to illustrate this part of the subject. Finally the examination of crystals in convergent light was dealt with.

The lecture was illustrated throughout by means of projection apparatus invented and designed by the lecturer himself, an important feature of the apparatus being the form of the polariser in which a modified double-image prism was employed instead of the usual Nicol. The lecturer explained that the spar required for this particular prism was only about one eighth of that required for a Nicol prism of the same aperture.

ABSTRACTS

"A New Double Prism." By A. GRÜNERT, *Z. f. Vermess.* 47 (1918), 128.

The Bauernfeind prism system used in geodetic work gives a small field of view and not very bright images. The author has invented a modification of the ordinary pentagonal prism. This is illustrated in the diagram. As in the pentagonal prism, the surfaces I and II are at right angles, and the silvered surfaces III and IV enclose an angle



of 45°. In addition there is a surface V which is parallel to I. The prism is made up of two pieces of glass, the surface of separation VI being parallel to IV. The two portions are cemented together in the upper half only. The path of a ray of light *a* through the upper half is shown thus – – – –, while the path in the lower half is shown thus.....

J. S. A.

"A New Double Prism." By SCHELLENS, *Z. f. Vermess.* 47 (1918), 225.

The author of this paper criticises the Grünert prism described in the previous abstract. He considers that the prism will not have any great practical value, chiefly because the light which enters from the right-hand side will have a very small field of view. From a critical examination of the field of view he concludes that the disadvantage of the smallness of the field is even greater than in the case of the Bauernfeind system.

J. S. A.

"British and German Lenses." *Brit. Journ. Photography*, 66 (3rd Jan. 1919), 2.

Purchasers of photographic lenses have been content to assume that a German lens was, as a matter of course, superior to a British one. However this may have been, British manufacturers, as a result of great improvements introduced during the war, have been able to produce lenses which are not only as good as German ones, but are decidedly superior to them. Some idea of the advance made can be gathered from the fact that in aerial photographs taken with all-British lenses at a height of 15,000 feet it has been possible to detect the presence of barbed wire. It is suggested that dealers in photographic lenses should have their lenses tested at the National Physical Laboratory in order that they may gain a thorough knowledge of their performance.

J. S. A.

"Aeroplane Photography." By ARTHUR BROCKER, Jun., and L. J. R. HOLST. (Reprint from *Aviation*), *Brit. Journ. Photography*, 66 (21st Feb. 1919), 84.

The authors draw attention to the important rôle aeroplane photography is likely to play in the future in connection with survey work. This would include the detailing of maps not yet complete, the mapping of hitherto unchartered territory, the location of sites for dams for irrigation work, the location of railroads and waterways through mountainous country, and the establishment of aerial routes and emergency landings in vast wooded tracts. A number of the problems connected with aeroplane photography are discussed, and a description is given of the Brock camera which has been designed for use in connection with contour mapping.

J. S. A.

"Taking Photographs from Aeroplanes and Balloons." By Lt. J. A. LEFRANC. *La Nature*; Abstract in *Scientific American Supplement*, 87 (25th Jan. 1919), 60.

This article is one of a series dealing with the evolution of German aviation. It gives a detailed account, illustrated by a number of photographs and diagrams, of several types of aerial cameras used by the Germans. Of special interest is the description of a film camera with which it is possible to obtain automatically a large number of views which are perfectly joined one to the other. Mention may also be made of the use in certain types of camera of an electric heating device placed in the dark chamber. The object of heating the apparatus is to increase the sensitiveness of the plates and to avoid the phenomena of condensation. The article contains an account of many of the problems and difficulties encountered in aerial photography.

J. S. A.

"Lenses for Aerial Photography." *Photographic Journ.* 59 (April, 1919), 114, 121, 122.

Three papers describing lenses for aerial photography designed by Messrs. Taylor, Taylor and Hobson, Ltd. ("Aviar" lens), Messrs. Ross, Ltd. ("Xpres" and "Airo Xpres" lenses), and Messrs. Aldis Bros. The points in which these lenses are superior to similar ones of German design are discussed.

J. S. A.